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# A TECHNIQUE FOR EVALUATING FUEL AND HYDRAULIC FLUID BALLISTIC VULNERABILITY

## INTERIM REPORT
## AFLRL NO. 89



By

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A relatively inexpensive ballistic test procedure has been developed for evaluating the relative fire vulnerability of various fluids of interest for Army applications. The technique employs 20 mm HEIT projectiles fired into partly-filled fluid containers. It yields repeatable results which establish both transient fireball effects and residual → over

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burning tendencies. Appropriate experimental procedures and conditions, such as target fluid temperature, were established, and the efficacy and repeatability were evaluated by conducting a total of 184 experiments, 81 of which are tabulated herein. These latter experiments were conducted with fire-safe fuel (FSF) and fire-resistant hydraulic fluid (FRH) candidates. The resulting experimental data agree with flammability measurements made with laboratory and bench-scale techniques and provide an apparently realistic assessment of ballistic vulnerability. It is planned to evaluate the realism of the ballistic exposure by arranging for a series of Army-conducted full-scale ballistic tests.

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# FOREWORD

This report was prepared at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, under DOD Contracts Nos. DAAG53-76-C-0003 and DAAK70-78-C-0001. The project was administered by the Fuels and Lubricants Division, U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Fort Belvoir, Virginia 22060, with Mr. F.W. Schaekel, DRDME-GL, serving as Contracting Officer's Representative. The loan of a 20-mm rifle and the provision of a supply of 20-mm HEIT ammunition were arranged by the Project Manager—Vehicle Rapid Fire Weapon Systems, Rock Island Arsenal at the request of the Fuels and Lubricants Division of the U.S. Army Mobility Equipment Research and Development Command (MERADCOM).

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# I. INTRODUCTION

## A. BACKGROUND

The fire-hazard problem has always been a matter of concern for both military and civilian heavy-equipment operators. The fire hazard is related not only to the obvious large volumes of fuel carried on board the equipment but also to the fluids used for lubrication and power transmission. The Army's large inventory of wheel/track equipment and the hostile environments in which this equipment must operate have caused considerable concern among military leaders. Throughout the years, considerable Army effort has been directed toward developing less flammable or completely fire-resistant fluids [1-11,13,14]*. With the development of new fluids, concurrent development of new relevant flammability evaluation test procedures has been required[8,9,12,14].

Research at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL) in recent years has been directed toward measuring the flammability/vulnerability of fire-safe fuels (FSF) and fire-resistant hydraulic fluids (FRH)[4,8,11,13,14]. It was found that bench-type screening tests must be followed by a more realistic test that would determine how a candidate fluid would perform under ballistic attack. Under this premise, a ballistic test procedure was established at AFLRL to explore and define the fire vulnerability of various fluids when exposed to a ballistic threat.

## B. OBJECTIVE

The purpose of this phase of research was to develop a relevant small-scale ballistic test that could be used to evaluate fire-safe fuel blends and to screen various candidate fire-resistant hydraulic fluids. It was intended that this procedure could be used as another standard fire- vulnerability procedure to define the relative resistance to burning. It could best be described as a very severe flammability test to evaluate both mist flammability and residual burning of candidate samples.

*Numbers in parentheses refer to references listed in the attached Bibliography of Reports and Publications on Fire-Safety Fluids by the U.S Army Fuels and Lubricants Research Laboratory.

## II. APPROACH

In order to accomplish the stated objectives, a series of 184 tests was conducted with 20-mm HEIT ammunition used against targets containing either fuel or hydraulic fluids. The ballistic tests were conducted in two series. The first series consisted of 23 tests using a different range and target configuration than the later series. The first series was used to evaluate a fire-safe fuel (FSF) containing a halogenated compound and provided important information on such parameters as fuel volumes, temperature-flash point relationships, and projectile performance. The results from this first series will not be discussed in depth since a new installation and new target configuration were subsequently established.

The second series consisted of 161 tests evaluating both hydraulic fluids and FSF blends. The FSF blends were evaluated at both elevated temperature, 77 °C (170 °F), and ambient temperature, approximately 25 °C (76 °F). A matrix of blends and replicates was prepared to assure random replicates of most combinations of additives. The series of hydraulic fluids consisted of duplicate tests at both ambient and high temperatures when adequate fluid was available, otherwise, at ambient temperature only.

## III. BALLISTIC FACILITIES

The experimental ballistic range had four major sections: a 20-mm Mann rifle assembly; a projectile velocity-measuring system (on the earlier series only); a fuel tank target, including a function plate (for fuel tests only); and video and 16-mm film recording equipment. Figure 1 illustrates the overall experimental setup.

The Hemi-cylindrical target enclosure was constructed from steel culvert pipe, 0.3-cm (1/8 in.) thick, 4.6-m (15 ft) wide, 2.7-m (9 ft) high, and 3.3-m (10.3 ft) deep. The concrete floor was 15.2-cm (6 in.) thick, and the backstop was a metal-clad, sand-filled wall. The 20-mm Mann rifle assembly was located under an open shed. The rifle barrel was mounted in a rigid universal cradle.

All firings and event recordings were remotely controlled. The rifle and high-speed camera were triggered by a solenoid. A 16-mm motion picture camera, a black-and-white video recorder, and a 16-mm slow motion camera were used to record the events following impact.

In the initial series of tests, three velocity screens were used to measure projectile velocity. The screens were spaced 1.5 m (5 ft) apart with the nearest screen 6.4 m (21 ft) from the muzzle of the rifle barrel. The elapsed times were recorded with an interval counter and oscilloscope, thus providing data for calculating projectile velocities (ca. 1000

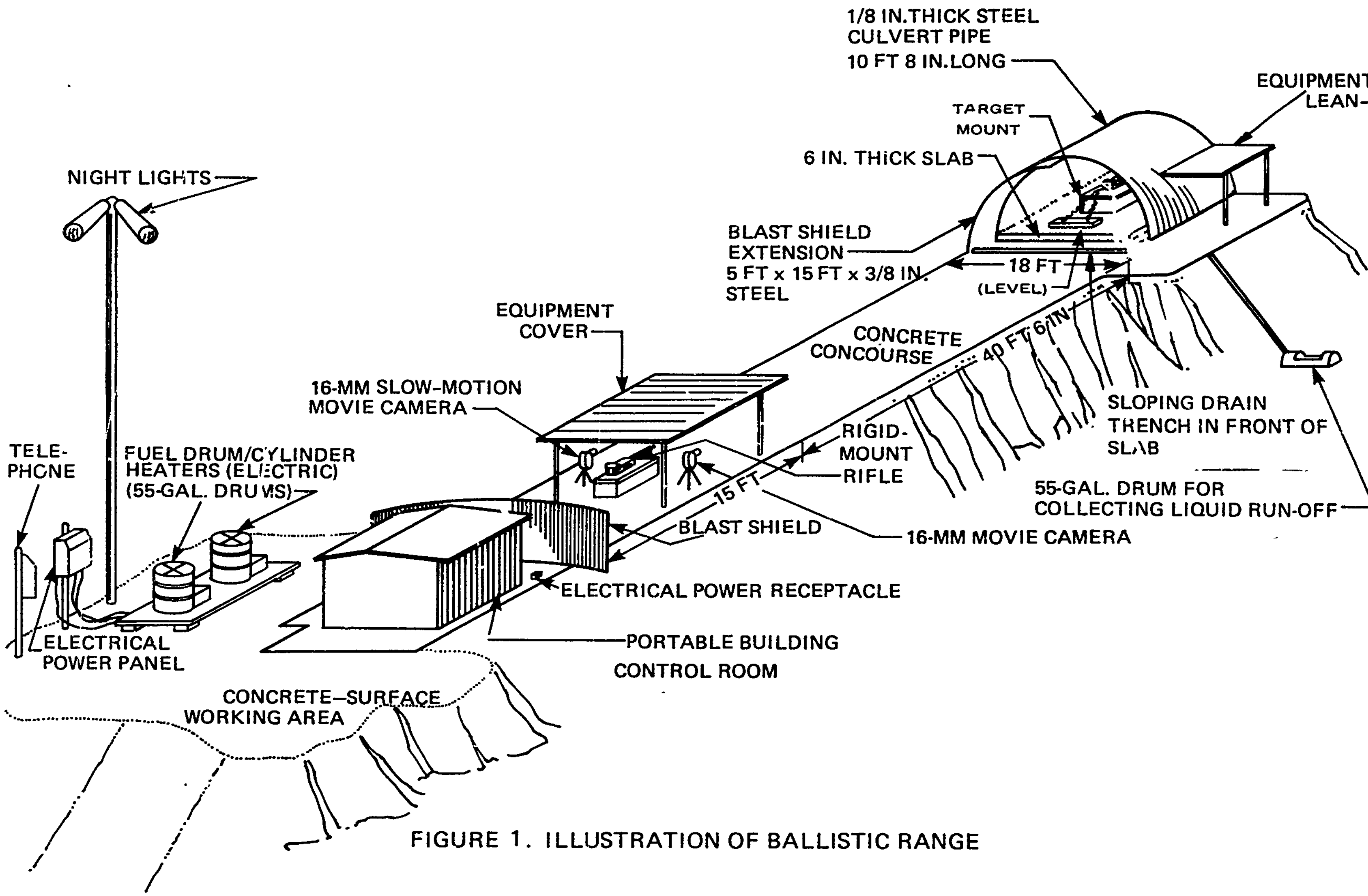


FIGURE 1. ILLUSTRATION OF BALLISTIC RANGE

m/sec). This procedure was discontinued after the first series since projectile velocity repeatability was considered to be adequate.

Figure 2 is an illustration of the fuel target assembly. A sand-filled iron pipe, 0.5 m (20 in.) in diameter, was located directly behind the target mount to absorb the impact and

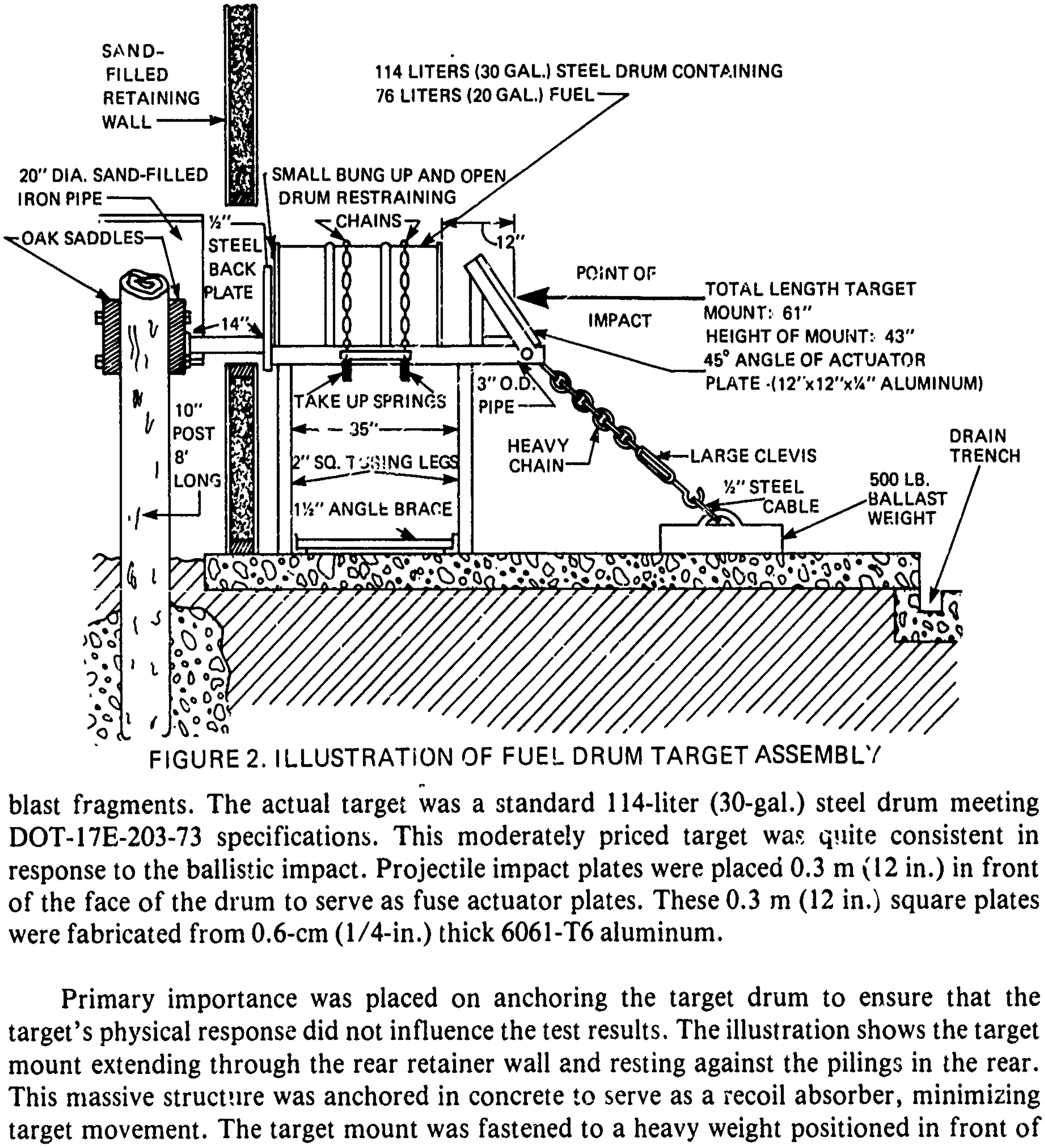


FIGURE 2. ILLUSTRATION OF FUEL DRUM TARGET ASSEMBLY

blast fragments. The actual target was a standard 114-liter (30-gal.) steel drum meeting DOT-17E-203-73 specifications. This moderately priced target was quite consistent in response to the ballistic impact. Projectile impact plates were placed 0.3 m (12 in.) in front of the face of the drum to serve as fuse actuator plates. These 0.3 m (12 in.) square plates were fabricated from 0.6-cm (1/4-in.) thick 6061-T6 aluminum.

Primary importance was placed on anchoring the target drum to ensure that the target's physical response did not influence the test results. The illustration shows the target mount extending through the rear retainer wall and resting against the pilings in the rear. This massive structure was anchored in concrete to serve as a recoil absorber, minimizing target movement. The target mount was fastened to a heavy weight positioned in front of the mount. It was not the intention to completely eliminate movement, but rather to stabilize the mount and ensure consistent response in each test. The early tests conducted in the first series showed that the target could not be rigidly anchored in concrete due to the tremendous forces experienced upon projectile impact.

Figure 3 is an illustration of the hydraulic fluid target installation. This setup uses the same mount and recoil-absorbing system as the fuel target, but the 2-liter cylinder (surplus military $CO_2$ container) is held in place by a modified saddle bolted to the mount. The target cylinder was pressurized to 67.5 atm (1000 psi) with nitrogen for each test. Also, this procedure did not use the actuator plate that was used in the fuel tests. It had been determined that better response was obtained when the actual cylinder received the ballistic impact.

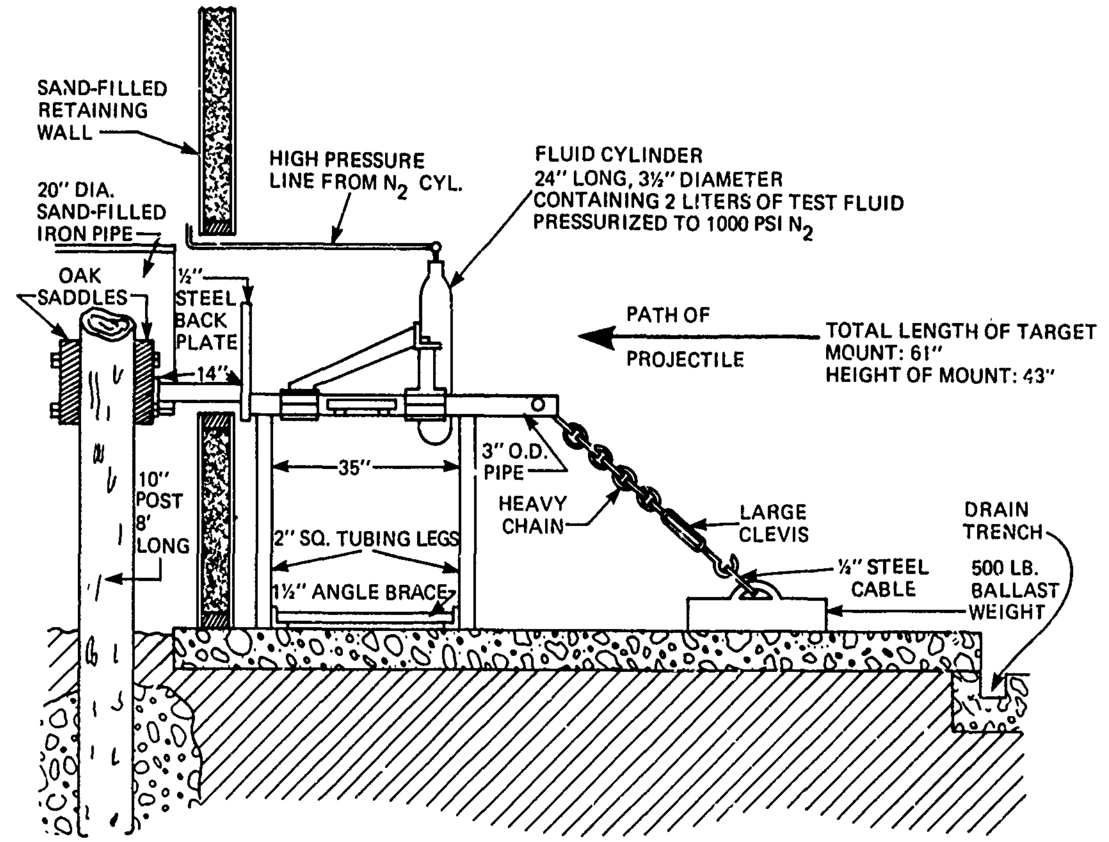


FIGURE 3. ILLUSTRATION OF HYDRAULIC CYLINDER TARGET ASSEMBLY

In order to obtain a relative measure of the size and intensity of the mist fireball occurring upon ballistic impact, two cloth curtains (12-oz ducking) were installed within the target enclosure. The curtains were installed on free-standing 1/2-in. pipe stands and positioned laterally two feet from the target face. Two curtain configurations were used, one longer than the other, the longest having approximately 8-in. overlay on the floor. The longer curtain, which touched the spilled fuel, was used to indicate wick-burning tendencies. The second (and shorter) curtain was placed so that it hung 18 to 20 in. from the floor surface and would ignite only when pool burning was observed. These two cloth objects simulated clothing or other personal gear which might be located in the vicinity of the point of impact. This technique successfully demonstrated that some mist fireballs were more intense than others, emphasizing the reduced intensity when an antimist agent was blended into the fuel. These curtains were used only in selected tests.

# IV. TEST FLUIDS

This ballistic test was developed to evaluate fire-safe fuel blends and fire-resistant hydraulic fluids. Fire-safe fuel will be described to allow a better understanding of the results obtained.

Fire-safe fuel research at AFLRL began more than ten years ago and involved high-internal-phase-ratio, fuel-in-water emulsions[2,5,7,9]. Present fire-safe fuel candidates comprise low-internal-phase-ratio, water-in-fuel emulsions, some of which contain antimist agents[4]. Various flammability tests have shown that diesel fuels containing water in concentrations up to 10%(v) have considerably reduced flammability hazards, even at temperatures well above the fuels' flash point. These fuels have essentially the same viscosity as the neat fuels as opposed to the earlier, semirigid fuel-in-water emulsions. These fuels are very difficult to burn when in the form of pools. The mist flammability is not greatly different from that of the base fuel, but mist flammability can be greatly reduced by the addition of low concentrations of antimist agents. These agents are normally very high molecular weight, long-chain polymers that prevent the fuel from disintegrating into very fine droplets that are highly flammable. The mechanisms by which these agents function are not fully understood, and they appear to vary among different classes of antimist agents. Fuels containing water, surfactant, and an effective antimist agent have been referred to and function as fire-safe fuels. The scope of the described series of ballistic tests was to investigate the effects of varying the concentration of the additives and the methods of blending. These results and yet-to-be conducted future investigations will assist development of an optimum formulation that would perform normally in an engine and provide the margin of fire safety that is required.

# V. TEST SEQUENCE

A ballistic test was conducted in three chronologically-arranged phases: (1) pretest preparations; (2) firing and recording of target response; and (3) post-test procedures. The three phases will be considered separately.

## A. PRETEST PREPARATIONS

1. **Fuel Preparation.** For both neat fuels and blends, 75.70 liters (20 gal) of fuel (or 1 liter of hydraulic fluid) are placed in the target vessel. If the fuel sample is to be tested at 77°C (170°F), the fuel is initially placed in the heaters for overnight equilibration. These heaters are 50-gal drums containing hot water slightly above test temperatures. This system eliminates "hot spots" possible with some other heating systems. Generally, the small cylinders of hydraulic fluids required only a few hours in these heaters to reach the desired test temperature.

2. **Site Preparation.** The rifle barrel is mounted and bore sighted for proper trajectory. The required cameras and video systems are loaded and positioned.

3. **Target Preparation.** The fuel drum is quickly removed from the heaters and placed on the target holder. The time required for this procedure is 2 to 3 minutes. Generally, the temperature of the fuel was approximately 175 °F at the time of removal. When the target was securely fastened, a small bung at the rear top of the fuel drum was removed to allow the temperature to be checked with a thermometer and recorded just prior to loading the weapon.

The hydraulic fluid samples were evaluated, as mentioned earlier, in 2-liter pressurized cylinders. One liter of sample was used for each test. If the test was to be conducted at elevated temperatures, the cylinder was plugged and placed in the previously-described heater for two hours. It was then taken from the bath and placed in the target mount. The filler plug was removed and replaced by the stainless steel line from the nitrogen cylinder. Nitrogen pressure on the sample was then adjusted to 67.5 atm (1000 psi), making the target ready to be tested.

## B. FIRING AND TARGET RESPONSE

1. **Firing.** Immediately before firing, the range alarm was sounded to alert personnel in the range area. The rifle was loaded, and the solenoid firing mechanism was actuated. The color motion picture camera and video recorder were manually started, and the solenoid firing mechanism was activated. There was a delay time of about two seconds to allow the high-speed camera to get up to speed prior to firing of the projectile. The high-speed camera operated until the 100 feet of film had been exhausted. However, the real-time camera and video camera were operated manually until the overall events had been properly documented.

2. **Target Response.** It is very difficult to obtain pictures which adequately illustrate the target/fuel responses that have been observed. To provide a suitable frame of reference for later discussions, the target responses will be shown graphically. Figure 4 is an illustration of the various responses that have been observed when a test fuel is subjected to ballistic evaluation. The sequence of six drawings illustrates essentially all the events that could occur, but it should be emphasized that the entire sequence may not occur in each test. These responses will, therefore, be discussed individually.

Figure 4.1 illustrates the flash that was observed from the incendiary round detonation only. This particular response is typical of the water calibration shot where the only recorded evidence was on the high speed camera film, since the duration is only a small fraction of a second.

Figure 4.2 is a moderate incendiary fireball that would be observed when a typical effective antimist agent is used in the fuel. The size of the fireball would vary depending

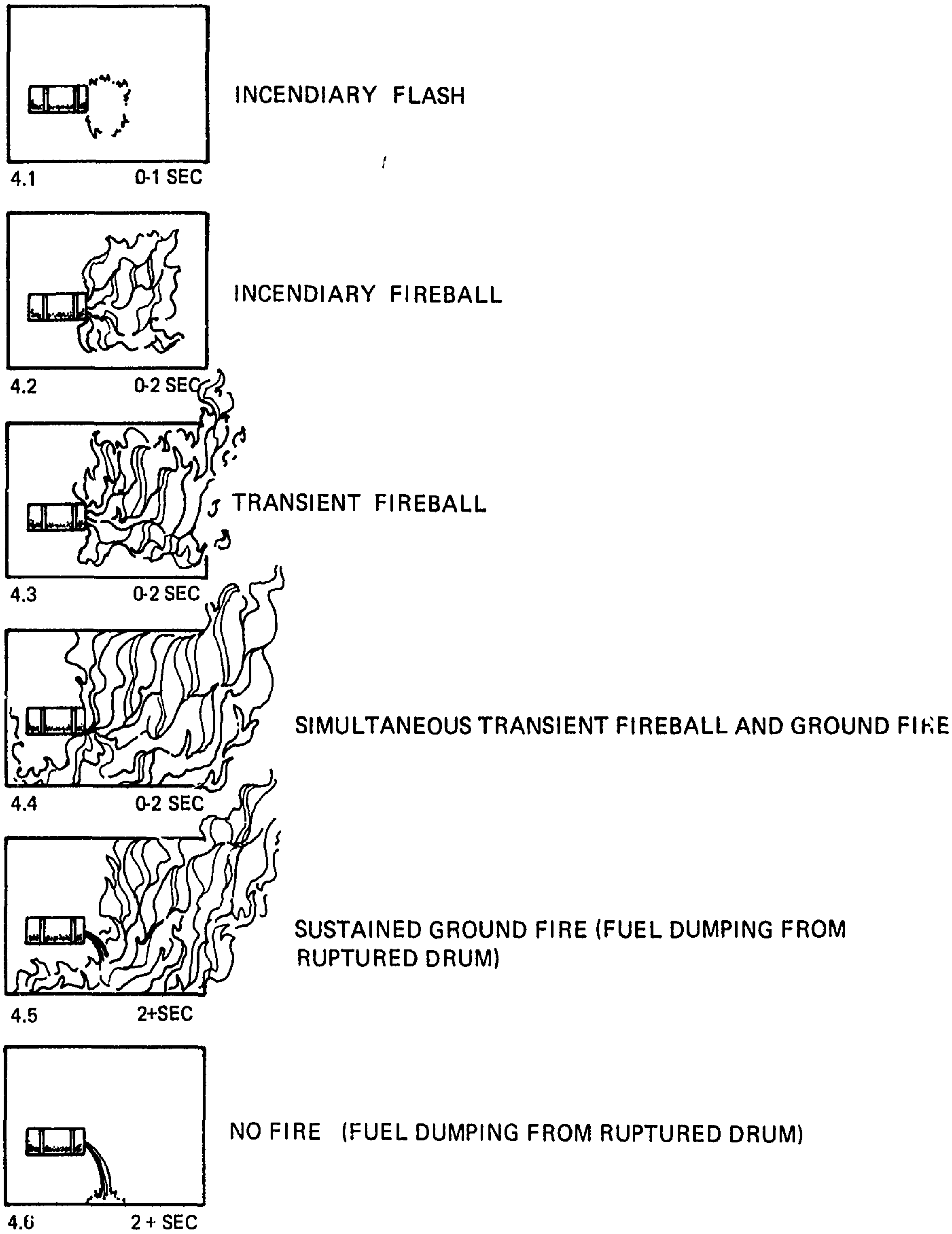


FIGURE 4. SCHEMATIC ILLUSTRATION OF TYPICAL OBSERVED EVENTS DURING BALLISTIC EVALUATION OF KEROSENE - TYPE FUELS

upon the amount and effectiveness of the antimist agent since some fuel would be consumed. This fuel burning would occur since it is impossible to prevent the fuel that is in actual contact with the hot incendiary fragments from igniting.

Figure 4.3 shows the transient fireball that has been observed in the absence of antimist agents. The fireball may vary slightly in size, but it essentially fills the target enclosure. This is the typical response of neat fuel, even at ambient temperatures below the fuel flash point. A mist cloud is formed by the ballistic explosion, thus producing an optimum flammability mode comprising finely dispersed fuel droplets in an open environment. The incendiary particles act as overwhelming ignition sources, and rapid flame propagation through the mist causes complete burning of the fuel cloud. The temperature of the fuel has some effect on the size of the fireball, but the transient fireball is not greatly affected by volatility of the fuel. It was observed on some occasions, when the fuel temperature was well below its flash point, that pool burning did not continue after the mist fireball had subsided.

Figure 4.4 shows the response frequently occurring with neat fuel when evaluated at test temperatures above the fuel flash point. This is the major problem that occurs when a fuel tank is struck by a ballistic ignition source. The mist fireball is destructive because it can act as an ignition source for other flammables, but it actually consumes only a very small percentage of the available fuel. However, it is the large volume of spilled fuel that causes the majority of damage when it continues to burn. Prevention of such ground fires is imperative for reducing personnel injury and lessening vehicle damage. Thus, the ideal role of fire-safe fuel blends is to reduce the mist fireball and eliminate ground fires.

Figure 4.5. Since the mist fireball lasts only one or two seconds, the majority of fuel is consumed in the ground fire that follows. Once the fuel is ignited, essentially all the fuel will be consumed before the ground fire subsides. This response is typical of neat fuel that has been heated to near or above its flash point.

Figure 4.6 shows the response that has been observed with fire-safe fuels containing antimist agents. In those tests, there was only a small incendiary fireball (Figure 4.2), and the remainder of the fuel simply spilled onto the floor. Examination of the test films has shown that this response is a normal occurrence when antimist fuels are tested, even when the temperature is above the flash point of the base fuel[4,8].

Figure 5 is an illustration of responses that have been observed when hydraulic fluids are evaluated under the described ballistic procedure. Once again, the series is intended to illustrate all the responses that have been observed. The extent varied from sample to sample. It should be noted that the entire sequence may not pertain to each sample.

Figure 5.1 illustrates the response of some experimental fluids where the only fire observed, even with the high-speed camera, was the typical flash from the incendiary ballistic projectile. This could indicate an ultimate degree of fire safety where the fluid is nonflammable with this exposure.

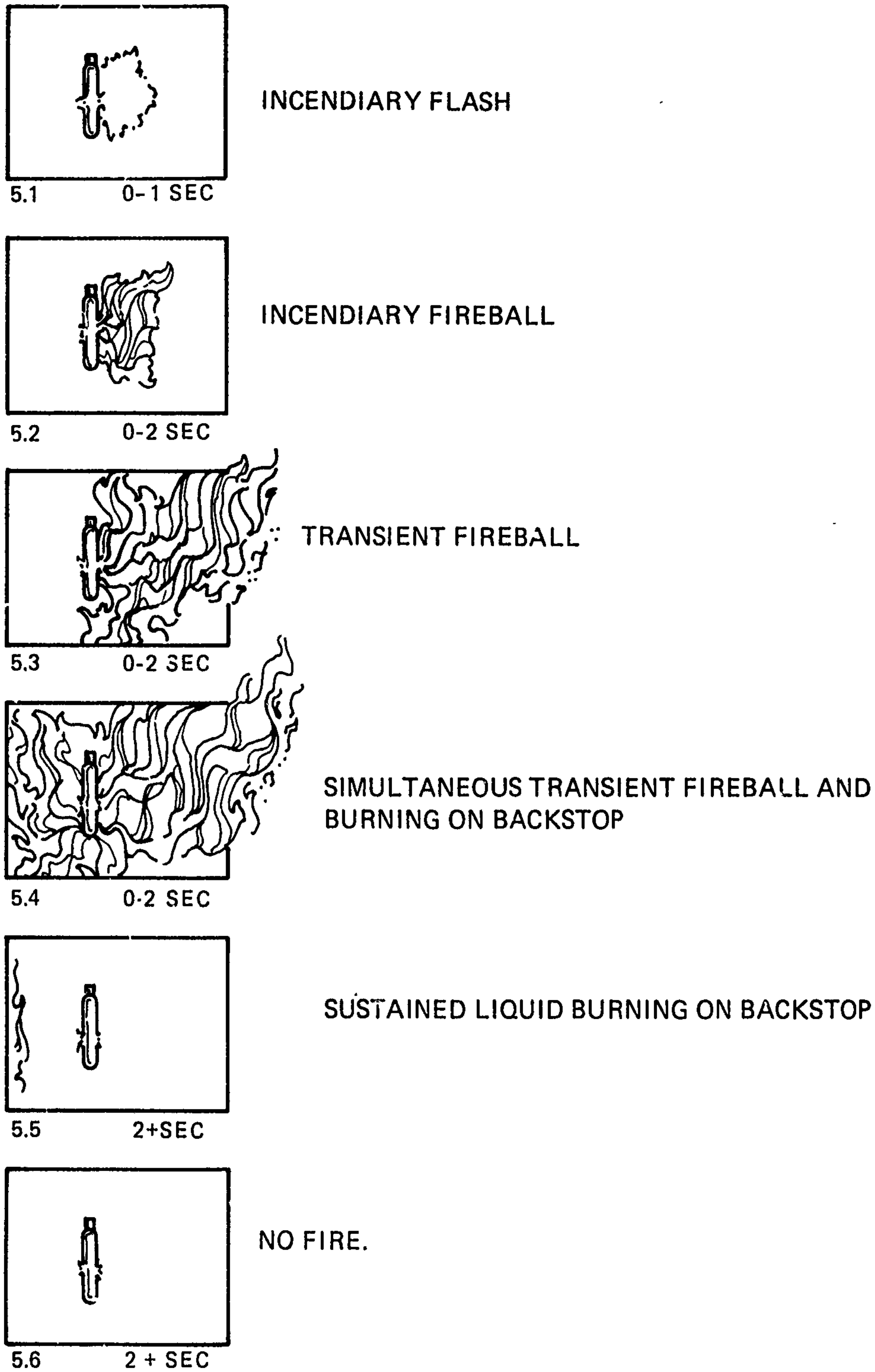


FIGURE 5. SCHEMATIC ILLUSTRATION OF TYPICAL OBSERVED EVENTS DURING BALLISTIC EVALUATION OF HYDRAULIC FLUIDS

Figure 5.2 illustrates the response that was observed when some fire-resistant fluids were evaluated. This is considered as an excellent rating since the size and duration of the fireball are extremely short.

Figure 5.3 is typical of the results that have been obtained when the majority of candidate fluids were evaluated. The normal response to the ballistic impact was a fireball, 2 m (7 ft) in diameter and approximately 1 second in duration. When the fireball collapsed, there was no trace of sustained burning.

Figure 5.4 is a response that was obtained with the MIL-H-5606 and MIL-H-6083 petroleum based fluids only. The mist fireball from these fluids was generally slightly larger than with the previously-mentioned fluids. The major difference was the sustained burning on the rear wall following the termination of the fireball. This result was obtained with these fluids without exception, regardless of the test fluid temperature.

Figure 5.5 is an illustration of the above-described burning that followed Figure 5.4. Since the test utilized only 1 liter of fluid, there did not seem to be enough fluid to support continued burning on the floor because the majority of the fluid was blown against the rear wall.

Figure 5.6 indicates results observed with some fluids following events corresponding to Figures 5.2 and 5.3. As a general rule, there was some fluid remaining in the cylinder at the end of each test.

## C. POST-TEST PROCEDURES

Activities after the firing primarily involved range preparation for the next shot. As a general rule, the only test that produced a substantial fire was the neat fuel at elevated temperatures. Therefore, the neat fuel fire (20 gal.) was allowed to burn to extinction, but the other blends (when required) were extinguished with a water spray. While the target vessel was cooling, the recording equipment was reloaded, if required, and the rifle barrel was cleaned. The target was removed, and the site was cleaned. After this brief procedure, the range was ready for the next shot.

# VI. DISCUSSION

It was discussed previously that this ballistic test procedure was established to provide a very severe flammability test to evaluate fire-safe fuel formulations and fire-resistant hydraulic fluids. Therefore, this discussion will emphasize the results obtained when these samples were evaluated, not from the standpoint of the flammability characteristics of the various samples, but from the standpoint of reliability and repeatability of the test procedure itself.

## A. BALLISTIC EVALUATION OF FSF

Table 1 is a compilation of the results obtained when FSF blends were subjected to ballistic evaluation. Initial tests of the base fuel only, conducted at ambient temperature, indicated that pool burning generally did not occur following the mist fireball under such

TABLE 1. FIRE-SAFE FUEL CANDIDATE RESPONSES TO BALLISTIC EVALUATION

**Target:** 114-liter (30-gal.) steel drum containing 76 liters (20 gal.) fuel; **Ammo:** 20-mm HEIT

| Fuel[1] | Test Temp. °C (°F) | Additives $H_2O$[2] | S[3] | AM[4] | Number of Tests | Number of Sustained Fires | Comments |
|---|---|---|---|---|---|---|---|
| DF-2 | Ambient | --- | --- | --- | 8 | 1 | Large mist fireball, retarded pool burning |
| DF-2 | 77(170) | --- | --- | --- | 3 | 3 | Large mist fireball, pool burning |
| DF-2 | 77(170) | 5 | 2 | --- | 3 | 2 | Large mist fireball, retarded pool burning |
| DF-2[5] | 77(170) | 10 | 2 | --- | 19 | 10 | Large mist fireball, retarded pool burning |
| DF-2 | 77(170) | 12.5 | 2 | --- | 2 | 0 | Mist fireball only |
| DF-2 | 77(170) | 15 | 2 | --- | 2 | 0 | Mist fireball only |
| DF-2[6] | 77(170) | 5 | 2 | 0.1 | 4 | 1 | Reduced fireball, retarded pool burning |
| DF-2 | 77(170) | 5 | 2 | 0.2 | 3 | 0 | Reduced fireball only |
| DF-2 | 77(170) | 10 | 2 | 0.1 | 2 | 0 | Reduced fireball only |
| DF-2 | 77(170) | 10 | 2 | 0.2 | 4 | 0 | Reduced fireball only |

[1]DF-2 fuel flash point approximately 62 °C (145 °F).
[2]Deionized water, % volume.
[3]Surfactant, % volume.
[4]Antimist agent, % weight.
[5]Fuel blends prepared using various blending techniques.
[6]Sample that burned contained intentionally degraded antimist agent.

conditions. This was not entirely unexpected since the bulk liquid must be heated to near its flash point in order to sustain burning. In other words, for this test series, the mist fireball did not serve as an overwhelming ignition source capable of producing pool burning when the test fuel temperature was below its flash point. The next series, evaluating the 60°-62 °C flash point base fuel, revealed that at 77 °C (170 °F), the ballistic impact produced a large mist fireball followed immediately by sustained pool burning. This fire was generally uncontrollable and was allowed to burn itself out.

The addition of 5%(v) water in the form of an emulsion produced a fuel that had a retarded ground fire only. By "retarded," it is meant that a fuel fire slowly developed, allowing time for an operator to extinguish the flame with an ordinary garden hose or other fire-extinguishing device. The ballistic procedure showed a correlation with the water concentration and with the method of preparation. The fuel blends containing 10-percent water, as a general rule, appeared less flammable than the 5-percent water blends. However, some of the 10-percent blends did not self-extinguish.

It was discussed previously that two flammability modes occur following ballistic penetration, sequentially, a mist fireball and pool burning. The bulk of the fuel is consumed by pool burning, and this type of burning may therefore be considered the primary hazard. However, the mist fireball can act as a primary ignition source causing severe injury to personnel and extensive damage to equipment.

Since the addition of only water eliminates pool burning, an antimist agent is required to eliminate the hazard associated with mist fires. Ballistic test results have shown that with the addition of even 0.1% (w) of AM-1 antimist agent, the mist fireball can be essentially eliminated. It was also demonstrated that even 5-percent water when incorporated with a good antimist agent produced an acceptable fire-safe fuel as determined by this test.

## B. BALLISTIC EVALUATION OF FRH

Ballistic evaluation of various hydraulic fluids has shown a tremendous difference in response of these fluids to ballistic impact. Table 2 lists the fluids that were evaluated and

TABLE 2. HYDRAULIC FLUID RESPONSES TO BALLISTIC EVALUATION

**Target:** 2-liter cylinder containing 1 liter of fluid under 67.5 atm of $N_2$ pressure; **Ammo:** 20-mm HEIT

| Fluid | Fluid Type | Test Temp, °C(°F) | Fluid Flash Point, °C(°F) | Number of Tests | Number of Sustained Fires | Comments |
|---|---|---|---|---|---|---|
| MIL-H-5606 | Petroleum Base | Ambient | 103(218) | 7 | 7 | Large fireball, residual burning |
| MIL-H-5606 | Petroleum Base | 77(170) | 103(218) | 2 | 2 | Large fireball, residual burning |
| MIL-H-6083 | Inhibited Petroleum Base | Ambient | 102(215) | 3 | 3 | Large fireball, residual burning |
| MIL-H-6083 | Inhibited Petroleum Base | 77(170) | 102(215) | 1 | 1 | Large fireball, residual burning |
| MIL-H-13919B | Petroleum Base | Ambient | 140(285) | 1 | 0 | Large fireball |
| MIL-H-13919B | Petroleum Base | 77(170) | 140(285) | 1 | 1 | Large fireball, reduced residual burning |
| MIL-H-83282 | Alpha-Olefin | Ambient | 226(437) | 3 | 0 | Fireball only |
| MIL-H-83282 | Alpha-Olefin | 77(170) | 226(437) | 1 | 0 | Fireball only |
| MIL-H-46170 | Inhibited Alpha-Olefin | Ambient | 224(434) | 3 | 0 | Fireball only |
| MIL-H-46170 | Inhibited Alpha-Olefin | 77(170) | 224(434) | 1 | 0 | Fireball only |
| Commercial Fluid | Phosphate Ester | Ambient | 194(380) | 3 | 0 | Reduced fireball only |
| Commercial Fluid | Phosphate Ester | 77(170) | 194(380) | 1 | 0 | Reduced fireball only |
| MS-6 | Silicone | Ambient | 277(518) | 1 | 0 | Reduced fireball only |
| MS-6 | Silicone | 77(170) | 277(518) | 1 | 0 | Reduced fireball only |
| Experimental | Silicone | Ambient | 282(540) | 1 | 0 | Reduced fireball only |
| Experimental | Silicone | 77(170) | 282(540) | 1 | 0 | Reduced fireball only |

the responses that were observed. In general, the petroleum-base fluids were more flammable than the other fluids. This is not unexpected since various other flammability tests[13,14] had indicated similar results. The type of flammability hazards being evaluated are fluid resistant to mist flammability and to sustained pool burning. Although the amount of fluid was limited to one liter, that quantity was enough to produce sustained burning on the rear wall of the target enclosure. It was determined that temperature was not a factor, probably because the flash point was considerably higher than the test temperatures in most cases. The samples with flash points below 150°C (302°F) usually exhibited residual burning. The only exception was the MIL-H-13919B hydraulic fluid. This petroleum-base fluid had a higher flash point than did the MIL-H-6083 and MIL-H-5606 fluids and showed marginal residual burning only when evaluated at the elevated

temperature. Hence, these results suggest a possible relationship between flash point and residual burning when evaluated according to this test procedure.

## VII. CONCLUSIONS

A new, more severe, fluid flammability test procedure has been needed to supplement bench scale fluid flammability evaluations presently being used in the Army's fluid fire safety research program. Critical review of results obtained thus far indicates that this goal has been achieved with the ballistic test procedure described herein. A relatively high fluid test temperature was selected with the objective of providing a relatively severe fire-hazard exposure. On this basis, the test procedure appears to provide a realistic assessment of the ballistic vulnerability of candidate fire-safe fuels and fire-resistant hydraulic fluids. The repeatability and reliability of the method have been shown to be excellent. In addition, the validity of the apparent realism of the selected test procedure will be determined by arranging for a series of Army-conducted full-scale tests.

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